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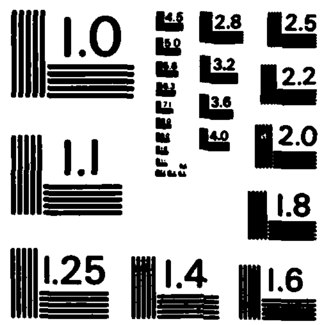
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Bolt Beranek and Newman Inc.

12

Report No. 5774

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Combined Quarterly Technical Report No. 33

Pluribus Satellite IMP Development
Mobile Access Terminal Network

May 1984

Prepared for:
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This Quarterly Technical Report describes work on the development of Pluribus Satellite IMPs: and on shipboard satellite communications.

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PLURIBUS SATELLITE IMP DEVELOPMENT
MOBILE ACCESS TERMINAL NETWORK

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Attention: Program Management

Table of Contents

FIGURES

1 INTRODUCTION

This Quarterly Technical Report is the current edition in a series of reports which describe the work being performed at BBN in fulfillment of several ARPA work statements. This QTR covers work on several ARPA-sponsored projects including (1) development of the Wideband Network, and (2) development of the Mobile Access Terminal Network. This work is described in this single Quarterly Technical Report with the permission of the Defense Advance Research Projects Agency. The work on the Mobile Access Terminal Network under contract 0408 has been completed. Some of this work is a continuation of efforts previously reported on under contracts DAHC15-69-C-0179, F08606-73-C-0027, F08606-75-C-0032, MDA903-76-C-0214, MDA903-76-C-0252, N00039-79-C-0386, and N00039-78-C-0405, and N00039-81-C-0408.

2 PLURIBUS SATELLITE IMP DEVELOPMENT

During the quarter, the Wideband Network continued to operate at 3 Mb/s. Several additional sites were brought up on the channel, either for the first time or following a lengthy outage due to equipment unavailability, bringing the total number of sites up to seven. BBN's activities during the quarter concentrated on Wideband Network operations, task force working meetings, PSAT software work, BSAT software development, and PSAT translator development. This report contains a detailed discussion of the satellite channel burst rearrangement algorithm used by the BSAT.

2.1 Wideband Network Systems Integration Activities

The PSAT software bug limiting the size of the control subframe was fixed during January, making it possible to operate the Ft. Monmouth site on the channel. On February 7, five sites were brought up on the channel for an extended period for the first time. An ESI-A was delivered to Ft. Huachuca during February. The Wideband Network task force visited Ft. Huachuca during the week of February 12 and successfully brought the site up on the channel for the first time.

An ESI-A was delivered to DCEC on March 19. The DCEC site had loaned its ESI to Ft. Monmouth to allow that site to be brought

up sooner. There were now seven sites which had their full complement of equipment.

At its April 11 meeting, the EISN steering committee decided that the site originally planned to be at MIT in Cambridge would be relocated to BBN (also in Cambridge) because of problems with finding a suitable site on the MIT campus which was free of RF interference.

2.2 Wideband Network Operations and Maintenance

Several minor equipment outages occurred during the quarter. The Ft. Monmouth earth terminal was down for several days at the beginning of February because of the improper power calibration of its 75-watt high-power amplifier (HPA). The Lincoln earth terminal was out of service for several days toward the end of February because ice formed in the flexible waveguide. The problem was cleared up by the Lincoln staff, using a hair dryer to melt the ice. Repairs to the SRI earth terminal were completed on February 1. The earth terminal equipment at Ft. Monmouth failed on March 2. It was repaired by Western Union on March 7.

During February and the first half of March, the SRI Burst Test Modem (BTM) was substituted for the High Speed Packet Modem

(HSPM) while the HSPM was being repaired by Linkabit. The HSPM was returned to SRI and installed on March 16. The Lincoln ESI-A experienced many unexplained "lock-ups" during March and April. This "lock-up" state could only be cleared by power cycling the ESI-A. Finally, at the end of April, the ESI-A's Interface Codec and Control Unit (ICCU) was returned to Linkabit for repairs. The ISI ESI-A was down for an extended period during April. It was finally restored to operation during the week of April 23, when Linkabit visited ISI as part of a task force meeting.

During February, both the RADC and Ft. Monmouth PSATs experienced two-day outages due to memory bus problems. A problem was found with the DCEC PSAT after the ESI-A was installed on March 19. BBNCC was able to track the problem to a faulty Satellite Modem Interface (SMI) which was replaced on March 28. On March 15, the lab air conditioning failed at RADC. The PSAT operated at elevated temperatures for over 8 hours and exhibited intermittent problems for several weeks after that. BBNCC field service was dispatched to the site on March 29, and after replacing a bad processor card and SMI, were able to restore the PSAT to operational status on April 2. The DCEC PSAT failed again in early April. This time BBNCC tracked the problem to another broken SMI and replaced it in time for a demonstration for the EISN steering committee on April 11. The Ft. Huachuca site was powered down because of administrative difficulties during the

period March 12-27.

2.3 Wideband Network Task Force Activities

The Wideband Network task force convened at Ft. Huachuca during the week of February 12. They succeeded in installing an ESI-A and bringing the site up on the channel. Some progress was made in understanding the ESI's problem in generating Test and Measurement data.

The task force met again at ISI during the week of April 23. Progress was made in testing the ESI with a reduced interburst padding. Interburst padding was reduced from 1024 to 768 channel symbols. Further progress was made in understanding the problems associated with getting the ESIs to generate T&M data reliably. A problem had been encountered while trying to run the network with more than 4 streams on the channel. Some progress was made in characterizing and isolating this problem during the April task force meeting.

2.4 BSAT Software Development

During February, code was added to the BSAT to handle Local-from-ESI and Local-to-ESI packets. These included the ESI Time

Request and ESI Time Reply packets needed for the ESI-B. Code was also added to the Datagram Scheduler for GFO Acquisition and for setting the ESI parameters.

In March, code was added to enable the BSAT to do stream requests from the TTY or from externally settable parameters. The internal time bases in the BSAT were rewritten to be confined to module boundaries. This enhances reliability and will make the BSAT host and channel modules more independent, in case some module needs to be restarted without disrupting the other modules.

In April, stream create, delete, and change worked in initial backroom testing. Also, using the ESI Simulator program, the BSAT initialized the "ESI", ranged, and sent leader packets. On April 19, short datagram bursts were sent via the ESI Simulator. A message rate of 630 messages per second was observed. During this month the decision was also made to eliminate the PSAT compatibility requirement.

2.5 BSAT Burst Rearrangement

2.5.1 Background

Data bursts on the satellite channel consist of a burst header followed by some number of aggregated user messages.

The burst header contains control information necessary to maintain proper network operation. Each user message consists of a header portion and a data portion. The header portion contains the standard Wideband data message header followed optionally by user-specified headers, such as an internet (IP) header. The data portion may be anything the user specifies: examples include speech and video packets, FTP packets, and network monitoring messages.

The Wideband Network provides forward error correction (FEC) coding to protect data transmitted on the channel from being corrupted by noise. The four coding rates, rate 1 (uncoded), rate 7/8, rate 3/4, and rate 1/2, provide increasing levels of protection. These levels of protection are also referred to as reliability levels, where low reliability refers to uncoded data, medium reliability to rate 7/8 and rate 3/4 coded data, and high reliability to data coded at rate 1/2.

Both the burst header and the message headers contain control information used in network control and message delivery. This information is always transmitted at high reliability to ensure that it arrives without bit errors. The coding rate at which the data portion of a message is sent, however, depends on the desires of the user. For instance, a bit error in digital speech is hardly detectable; therefore,

speech packets are usually transmitted at low reliability. Each message header contains a field which specifies at what reliability the data portion of the message is transmitted.

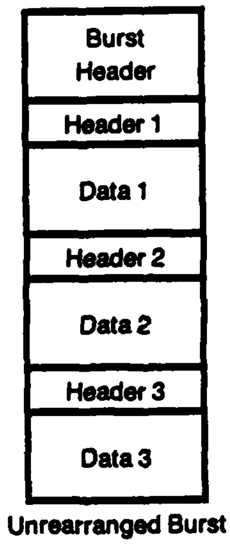
The consequence of this flexibility in allowing coding rates to be specified for different portions of the message is that bursts with many messages will have several pieces transmitted at different coding rates. The number of transitions between coding rates ("state changes") is dependent on how the header and data portions of the messages are arranged in the burst. Two different methods have been proposed, one of which is used in the PSAT and the other in the BSAT.

When aggregating a burst, the PSAT uses the simple technique of adding each new message in its entirety to the end of the current burst, resulting in an "unrearranged burst." In the BSAT, on the other hand, the channel scheduler and the uplink processor cooperate to send together messages whose data portions are to be sent at the same coding rate. They are grouped from high to low reliability. The messages are then split up into header and data portions. The header portions are grouped together; then the data portions are inserted in the same order as the corresponding headers. The result is a "rearranged burst."

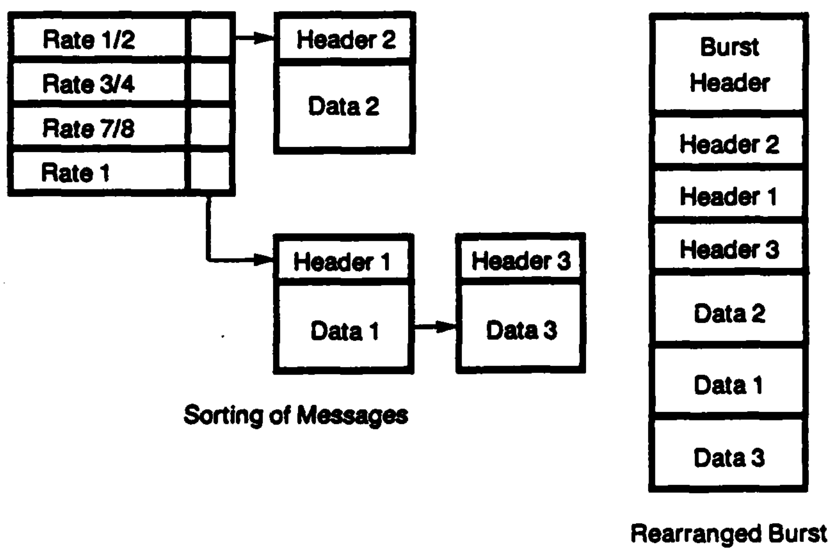
2.5.2 Advantages of Burst Rearrangement

Consider a burst containing three messages, the first with the coding rate for the data portion at rate 1, the second with the coding rate 1/2, and the third at rate 1 again. The header portion of each message is always sent at rate 1/2, the specified control coding rate. The unrearranged burst, formed by adding each message in turn to the end of the burst, is illustrated in Figure 1.

Figure 2 illustrates the steps involved in forming a rearranged burst containing these three messages. In this example, all of the message headers and the data part of message 2 are to be sent at coding rate 1/2. The data portions of messages 1 and 3 are to be sent at coding rate 1. The messages are first sorted by the coding rate specified for the data portion, starting with the control coding rate. The header portions are then added to the burst in sequence; then the data portions are added in sequence. This results in a burst which has all elements to be sent at each coding rate grouped together. The message headers and the corresponding data portions are also inserted into the burst in the same order, to facilitate the reconstruction of the individual messages from the burst when it is received.



Unrearranged Burst
Figure 1



Forming a Rearranged Burst
Figure 2

The arrangement of the burst has several effects on the operation of the satellite subsystem.

1. The unrearranged burst requires less processing during aggregation and deaggregation.

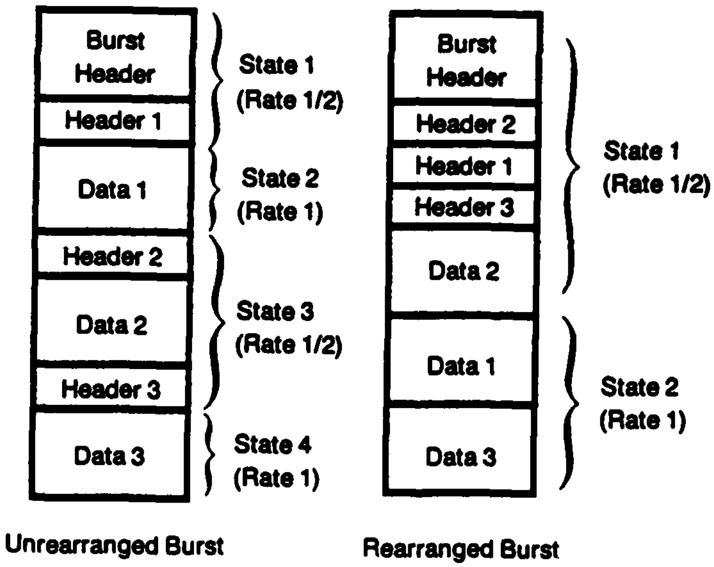
The basic aggregation decision when building an unrearranged burst is simple: if the message fits in the burst, add it to the end of the burst. In contrast, when building a rearranged burst, the messages must be checked in turn to see if they fit, then sorted by coding rate. Once all messages for the burst have been sorted, they can then be split into header and data portions, and each portion can be added to the burst in sorted order.

2. The rearranged burst has fewer state changes than the unrearranged one.

A state change occurs each time the coding rate changes within the burst. Each state is represented by a stateword in the burst header. The stateword indicates the coding rate for a particular portion of the burst and the length of that portion. During the *transmission of a burst*, the ESI encoder must do some additional processing each time a new state is entered. The ESI decoder must also do additional processing per state on the downlink. Thus, minimizing the number of state changes lowers the burst processing in the ESI Interface Codec and Control Unit (ICCU).

Figure 3 shows the unrearranged and rearranged bursts from the previous examples, with each state indicated. The unrearranged burst has four states; the rearranged burst has only two. Because of the nature of the rearrangement, no rearranged burst can have more than four states. Unrearranged bursts can have any number of states up to the limit of sixteen supported by the ESI.

3. Sometimes, more messages can be fit into a rearranged burst.



Comparison of Unrearranged with Rearranged Burst
Figure 3

As discussed in the previous section, the stateword limitation never constrains a rearranged burst. Therefore, only the constraint on the burst length has any effect. When the messages coming into the system are small and they have different header and data reliabilities, more messages can be fit into the rearranged burst. Figure 4 illustrates a case with short messages. In the unrearranged burst, the stateword limit is reached long before the burst length limit is. The rearranged burst contains many more messages, with fewer states.

One common example of a case with short messages is LPC speech packets, which are typically less than 100 bits long, while the maximum burst size is 2*16 bits.

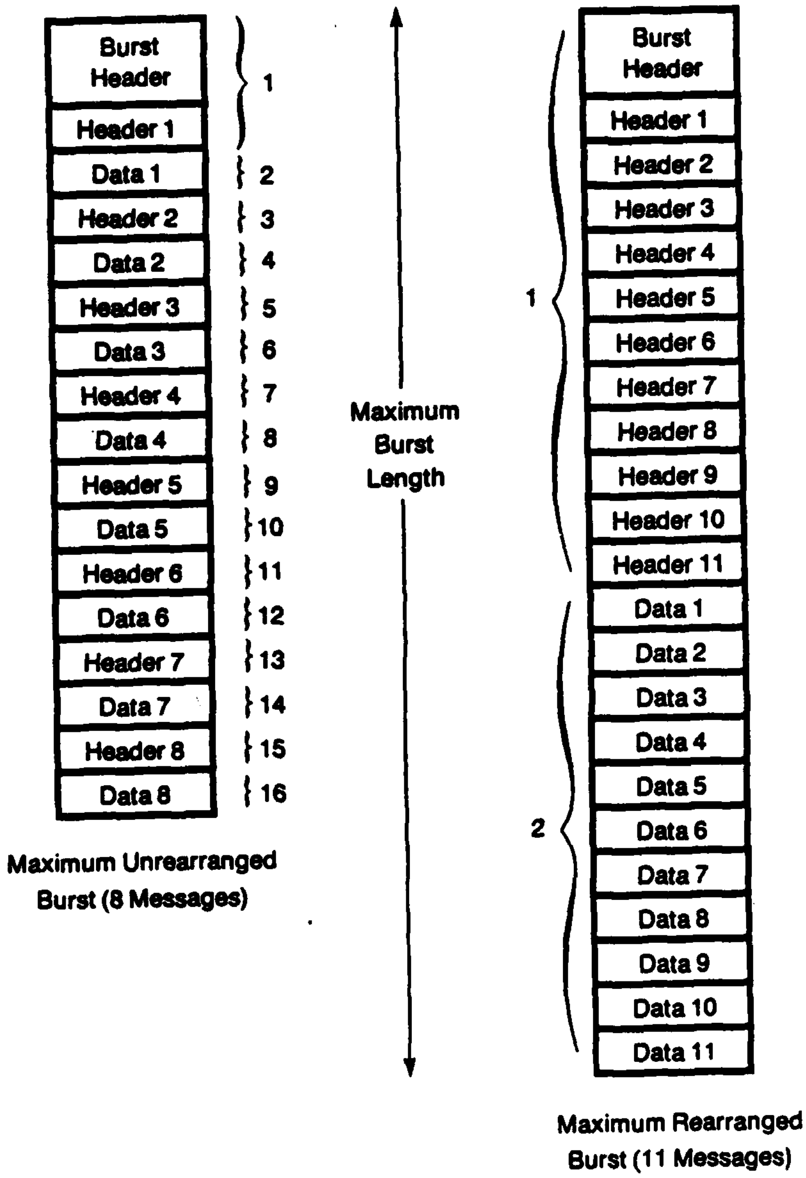
4. Datagram fragmentation is simpler when the burst is rearranged.

To allow for more efficient channel utilization, datagram packets can be broken into smaller bursts when there is not enough room for the datagram to be sent in one burst. This process is called datagram fragmentation.

The arrangement of the burst determines where a burst can be split for fragmentation. For example, a CRC cannot be split into two pieces because the hardware that checks the CRC expects each packet to be terminated with an intact CRC. Similarly, a burst cannot be split in the middle of a coding tail, because the ESI would then be unable to encode and decode it. Different types of processing must be done to split a burst in the middle of a state and at the end of a state.

In the PSAT code, which uses unrearranged bursts, there are 20 separate cases which should be considered when deciding where to fragment a burst. While the BSAT fragmentation code, which deals with rearranged bursts, has yet to be written, only five separate cases have been identified for consideration during fragmentation.

One of the major reasons for this disparity is that the rearranged bursts are sent as a single packet, while the unrearranged bursts have a control packet followed by data packets containing each message in the burst. Each packet begins with a SYN/DLE/STX and ends with a CRC, and neither can be split. Since the rearranged burst has



Maximum Size Burst
Figure 4

only a single packet, having either a SYN/DLE/STX or a CRC in the middle of a burst need not be considered.

A second reason why there are fewer cases in the fragmentation of rearranged bursts is that the state changes in a rearranged burst are fewer and occur in a more defined way. The first state in a rearranged burst always contains the burst header, followed by all message headers, followed possibly by some message data. All other states only contain message data. Consequently, the number of cases which need to be considered at each stage of fragmentation can be restricted to those which are possible.

Rearranging the burst and grouping the data by forward error correction coding level ensures that the ESI stateword limit is not exceeded; thus, more data packets can be aggregated into each burst, making more efficient use of the satellite channel. Burst rearrangement requires the ESI to do less uplink and downlink processing on each burst. Therefore, the size of the interburst padding can be reduced. Finally, burst rearrangement simplifies the datagram fragmentation algorithm by reducing the number of places where the burst may not be split.

2.5.3 Implementation

In downlink processing, the individual message must be reconstructed from the information sent in the burst. For an unrearranged burst, each message simply begins where the burst header or the previous message ended and extends for the number of words indicated in the message's header. With burst rearrangement, it is necessary to be able to find the data portion that goes with each header portion of the user's messages. A complication can occur if the burst has been received with errors. The burst format has been designed so that bit errors in the message data do not prohibit message reassembly, and errors in the message header usually will only destroy the mangled message and the message that precedes it in

the burst.

The burst has three sections: the burst header, the concatenated message headers, and the concatenated message data. The burst header format is described in the PSAT Technical Report #4469, though some minor changes have been made to accommodate the new ESI. The burst format for datagram and stream messages is discussed in this section.

```
+---------------+
|    burst      |
|    header     |
+---------------+  <--- header origin
| msg 1 header  |
| msg 2 header  |
:               :       (header plus "rlen" portion of message)
:               :
| msg N header  |
+---------------+  <--- data origin
| msg 1 data    |
| msg 2 data    |
:               :       (rest of message, if any)
:               :
| msg N data    |
+---------------+
```

The HAP header of the message is always sent at the highest reliability. In addition, the user may request that additional words immediately following the header be sent at high reliability. This may be used to protect an IP or TCP header, or other data, and, in effect, makes the boundary between header and data in the message move closer toward the end. This extra high reliability data length is indicated in the "rlen" field of the Type of Service word in the HAP header.

The message headers (plus any data portion indicated by the "rlen" field of the header) are collected together at the beginning of the burst, and the data portion of the messages, if any, is placed at the end of the burst. The order of message headers exactly matches the order of message data portions.

In the downlink process, the problem is reconstructing the user messages from information in the burst. Our current design accomplishes this without adding any extra words to the size of the burst by re-using the packet length field in the HAP header.

The message length field is overwritten as the message is copied into the burst. The software checksum of the resulting header is computed and saved.

The total length of the burst can be determined from information in the burst header. The first message header begins just after the burst header. Each message header contains the value of "rlen" which, along with the constant size of the message header, indicates the number of bytes of the message in the "header" portion of the burst. This suffices to find the beginning of the next header.

Each message header also contains the offset of the beginning of its data in the burst. This offset is saved in the message length field of the HAP header. By subtracting the data offset in the current header from the offset in the next header (or from

the offset corresponding to the end of the burst) one can compute the length of the message's data portion.

The data position offset in the message header is in units of bytes past the data origin (see diagram). Since the offset for the first message is always zero, the first message header gives the data origin relative to the header origin. Although more complicated, bursts with rearrangement are not significantly more susceptible to channel errors than bursts without rearrangement. Errors in the data portion of the burst will not impair message reassembly. If a burst arrives with the proper length but with errors in the header (high reliability) portion, it is usually still possible to recover many of the messages in the burst.

With high reliability coding, the bit error rate is better than 1.0E-11. At 1.544 Mbps, one could expect an error about once every 19 hours. In practice, the error rate is even lower because some errors cause the burst to be discarded before deconvolution is reached. Thus, errors in the high reliability portion of the burst that can cause improper reassembly are infrequent.

If the first header is garbled (very unlikely), then, because it contains the data origin offset, the burst is completely lost. Any other header that is garbled (determined by testing the software header checksum) will eliminate the message of which it

is a part and the message that precedes it in the burst. This is because the length of the previous message is determined by subtracting the data offset in the previous header from the data offset in the current message. If a header is garbled so that "rlen" is wrong, then the current message and all following messages will be lost, since the beginning of the next header cannot be determined.

The unrearranged burst format has a similar but different problem. Each message header contains a packet length word which indicates to the PSAT SMI how many words follow. An error in the received value of the packet length can cause the PSAT SMI to prematurely end a message, to falsely detect a new message header, or even to absorb a number of later bursts from the channel causing them to be processed as message data instead of separate bursts. With rearrangement, there are no special packet length words, and errors in the header words of a message will not cause later channel bursts to be misprocessed.

2.5.4 Synopsis

Burst rearrangement is worthwhile because it reduces the amount of channel time wasted in coding rate state transitions. It also removes the number-of-messages limit that had been imposed by having a maximum of 16 statewords per burst, allowing more

messages to be sent in one burst in some common cases like voice packets. In addition, burst rearrangement significantly simplifies the burst fragmentation algorithm.

This is accomplished without extra overhead words in the burst. Even if some of the messages in a received burst have errors, our rearrangement technique is capable of recovering many of the other messages completely.

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